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~~GEORGE K. BURGESS, Director~~

Lyman J. Briggs, Director.

REPORT No. I-2

JULY 1, 1933.

CURRENT HYDRAULIC LABORATORY RESEARCH IN THE UNITED STATES.

WASHINGTON

REPORT ON
CURRENT HYDRAULIC LABORATORY RESEARCH
IN THE UNITED STATES.

Compiled by the Bureau of Standards
U. S. Department of Commerce
Washington, D. C.

Vol. I, No. 2. July 1, 1933.

INTRODUCTION.

The first quarterly report on current hydraulic laboratory research, issued by the Bureau of Standards on April 1, 1933, has aroused wide-spread interest in this country. Copies were sent initially to nearly two hundred interested institutions and individuals, and requests have come in for about 100 more copies. Fifty copies were also furnished Mr. O. C. Merrill, Chairman of the American Committee of the World Power Conference, to be taken to the Stockholm meeting of the World Power Conference in June and July of this year.

The spirit of cooperation shown by the heads of the hydraulic laboratories in this country has been very encouraging. The responses to requests for information have been prompt and quite complete. Unfortunately, because of a misunderstanding, the reports from several laboratories were not released in time to be included in the first quarterly report. However, they are included in the present report.

Abstracts of reports of completed projects are desired and will be published in the quarterly reports whenever furnished. A statement is also desirable as to where the report has been or is to be published, or if not published, whether the report is available for loan.

It is planned to issue the third report on October 1, 1933. Please send all material for inclusion in this report to the Bureau of Standards before September 15. It is requested that the form given in the following key be used in reporting projects. This will simplify the task of editing the information furnished.

CURRENT PROJECTS IN HYDRAULIC LABORATORIES.

(Key)

(a) Title of project:
(b) Project conducted for:
(c) Conducted as:
(d) Investigators:
(e) Correspondent:
(f) Purpose:
(g) Method and Scope:
(h) Progress:
(i) Remarks:

CALIFORNIA INSTITUTE OF TECHNOLOGY.

(100) (a) MODEL INVESTIGATIONS OF SILTING PROBLEMS AT SEAL BEACH.
(b) The Los Angeles Gas & Electric Corporation and the Los Angeles County Flood Control District jointly.
(c) General scientific research to solve a particular problem.
(d) Dr. Robert T. Knapp & V. A. Vanoni with Major Charles T. Leeds as consultant.
(e) Professor R. L. Daugherty.
(f) To determine the probable effect of a change in the channel of the San Gabriel River, which now discharges into Alamitos Bay some distance from the point where the bay is connected with the ocean. This causes the bay to silt up. The Flood Control engineers propose to cut a new river channel so that it will discharge into the channel connecting the bay with the ocean. But the Seal Beach steam plant of the Los Angeles Gas & Electric Corporation is located along this channel and draws condensing water from it. It is feared that the change will cause this channel to silt up and thus interfere with the supply of condensing water.
(g) A model basin has been constructed. In it there has been reproduced to scale a portion of the bay, the ocean, the connecting channel and the present outlet of the river. The river will be caused to discharge its various rates of flow while the ocean will reproduce its tide cycles. The effects will be observed both for the present river course and with the proposed new channel.
(h) Model is completed and work is now under way.
(i) This work has been financed by the Los Angeles Gas & Electric Corporation and the Los Angeles County Flood Control District. H. L. Masser and J. G. Rollow of the former and E. C. Eaton, Chief Engineer of the latter together with Major C. T. Leeds have made the work possible.

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(101) (a) THE CHARACTERISTICS OF A CENTRIFUGAL PUMP WHEN OPERATED UNDER ABNORMAL CONDITIONS.
(b) Laboratory problem only.
(c) General scientific research and thesis for Haynes.
(d) Dr. R. T. Knapp and B. C. Haynes, and others as assistants.
(e) Professor R. L. Daugherty.
(f) To investigate characteristics when a centrifugal runs in both directions, with water being pumped and also with water flowing down backwards through the pump. This study is of interest for cases where the power suddenly fails for a centrifugal pump with a high lift and a long discharge line in which the flow will reverse.
(g) The method is the usual one of testing a pump, save for the new conditions, which are brought about in the laboratory by a second pump which can pump water into the discharge line of the first pump.
(h) Work has been under way for the past year and is to be continued.

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(102) (a) INVESTIGATION OF VELOCITY DISTRIBUTION IN THE VOLUTE OF A CENTRIFUGAL PUMP IN THE NEIGHBORHOOD OF THE IMPELLER.
(b) Laboratory problem.
(c) General research for thesis for M. S. degree.
(d) R. C. Binder.
(e) Professor R. L. Daugherty.
(f) By a special instrument the magnitude and direction of the velocity of the water is measured at a number of points within the volute, thus supplying experimental information that has long been desired.
(g) As in (f)
(h) Work has been under way for a year. Much has been accomplished and it will be continued next year.

....

(103) (a) EFFECT ON EFFICIENCY OF A CENTRIFUGAL PUMP THROUGH REDUCING ITS CAPACITY BY BLOCKING OFF CERTAIN OF THE IMPELLER PASSAGES.
(b) Laboratory problem.
(c) For thesis.
(d) Keith Murdock.
(e) Professor R. L. Daugherty.
(f) Purpose is indicated by the title, except that there is a practical application when the overall efficiency may be better if a reduced discharge is desired by blocking off passages rather than by throttling the discharge.
(g) Usual methods of pump testing.
(h) Work has been under way for a year and is completed.

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(104) (a) FURTHER MODIFICATION OF THE THEORY OF CENTRIFUGAL PUMP DESIGN.
(b) College problem.
(c) For thesis.
(d) George F. Wislicenus.
(e) Professor R. L. Daugherty.
(f) To place the method of design on a sounder basis.
(g) Theoretical studies based on actual test data.
(h) Work has been under way for some time and is continuing.

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(105) (a) INVESTIGATION OF TRANSPORTING VELOCITIES OF SAND FOR USE IN MODELS.
(b) The laboratory.
(c) Thesis for Master's degree.
(d) W. F. Pruden and J. Sheffet.
(e) Professor R. L. Daugherty.
(f) As indicated by title.
(h) Work done during the past school year.

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UNIVERSITY OF CALIFORNIA.

(11) (a) MODEL STUDY OF BALLARD LOCK, LAKE WASHINGTON SHIP CANAL.
(d) Vinoy and Fries.
(e) Professor M. P. O'Brien.
(h) To be completed in May, 1933.
See Report I-1 for (b) and (i).

....

(12) (a) JET PUMPS.
(d) Ledgett.
(e) Professor M. P. O'Brien.
(f) Continuation of project on water jet pumps by O'Brien and Gosline reported at Pacific Coast Applied Mechanics meeting of the A.S.M.E., January 20-21, 1933.

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(13) (a) AIR-LIFT AND GAS-LIFT.
(d) O'Brien and Gosline.
(e) Professor M. P. O'Brien.
(f) Velocity of rise of bubbles as a function of viscosity and surface tension; theoretical and experimental investigation of lifts for water and oil.
See Report I-1 for (c) and (i).

....

(14) (a) STREAMLINE AND TURBULENT FLOW THROUGH GRANULAR MATERIALS.
(d) Givan and Hickox.
(e) Professor M. P. O'Brien.
See Report I-1 for (c) and (i).

....

(15) (a) REVERSED FLOW IN CENTRIFUGAL PUMPS.
(d) O'Brien and Gosline.
(e) Professor M. P. O'Brien.
See Report I-1 for (c) and (i)

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(16) (a) EFFECT ON EVAPORATION FROM STANDARD PANS DUE TO CHARACTER OF SURFACE OF PAN.
(d) Hickox.
(e) Professor M. P. O'Brien.

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(17) (a) TRANSPORTATION OF BED LOAD BY STREAMS.
(d) Cothran, Rindlaub, Wilson, Kurilow.
(e) Professor M. P. O'Brien.
(f) Determination of the minimum velocity required to start motion of five harbor sands.
(h) To be completed in May, 1933.
See Report I-1 for (c) and (i).

....

(18) (a) CHARACTERISTICS OF SIPHON SPILLWAYS.
(d) Saylor and Anderson.
(e) Professor M. P. O'Brien.
(f) Comparison of models with prototypes and determination of effect of air leakage on coefficient of discharge.
See Report I-1 for (c) and (i).

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(19) (a) BROADCRESTED WEIRS.
(d) Bartlett and Carter.
(e) Professor M. P. O'Brien.
(f) Comparison of model and prototype.
See Report I-1 for (c) and (i).

....

(20) (a) VORTEX MOTION ON THE SURFACE OF FLUIDS.
(d) Carter.
(e) Professor M. P. O'Brien.
(h) To be completed in May, 1933.
See Report I-1 for (c) and (i).

....

(21) (a) CAPILLARY POTENTIAL AND CAPILLARY FLOW IN SOILS.
(d) Colby.
(e) Professor M. P. O'Brien.
See Report I-1 for (c) and (i).

....

(22) (a) DISCHARGE COEFFICIENTS OF SHORT TUBES.
(d) Jones and Twigg.
(e) Professor M. P. O'Brien.
(f) Comparison of results with experiments of M. J. Zucrow on carburetor jets (Bull. No. 31, Eng. Exp. Sta., Purdue University.
(h) To be completed in May, 1933.
See Report I-1 for (c) and (i).

....

(23) (a) STIRRING CHEMICALS FOR WATER TREATMENT BY DISC FRICTION.
(d) Gayner.
(e) Professor M. P. O'Brien.
(h) To be completed in May, 1933.
See Report I-1 for (c) and (i).

....

(24) (a) TRAJECTORY OF NAPPE FROM SUPPRESSED SHARP-CRESTED WEIR AND PRESSURE ON FACE OF WEIR.
(d) O'Shaughnessy and Peterson.
(e) Professor M. P. O'Brien.
(h) To be completed in May, 1933.
See Report I-1 for (c) and (i).

....

(25) (a) EFFECT OF RADIAL RIBS ON END THRUST OF CENTRIFUGAL PUMPS.
(d) Nelson.
(e) Professor M. P. O'Brien.
(h) To be completed in May, 1933.
See Report I-1 for (c) and (i).

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HARVARD UNIVERSITY.

(106) (a) A STUDY OF THE FLOW OF WATER THROUGH SAND.
(b) Conducted as departmental research.
(c) Conducted as general scientific research.
(d) Investigators: Gordon M. Fair and Loranus P. Hatch, Associate Professor of Sanitary Engineering and Research Fellow in Sanitary Engineering, respectively.
(e) Professor Gordon M. Fair.
(f) To determine the filtration and expansion characteristics of sands used in water purification and, if possible, to aid in the study of the flow of water through the soil.
(g) Laboratory investigation consisting of a study of the characteristics of sands and of their behavior when subjected to flowing water.
(h) Study has been under way for three years and is almost completed and ready for publication.

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HYDROLOGICAL LABORATORY, U. S. GEOLOGICAL SURVEY, WATER RESOURCES BRANCH, DEPARTMENT OF THE INTERIOR.

(26) (a) PERMEABILITY TESTS CONDUCTED UNDER VERY LOW HYDRAULIC GRADIENTS.
(d) O. E. Meinzer, V. C. Fishel.
(e) O. E. Meinzer.
(f) The purpose of this experiment is to find out if there is a flow of liquids through porous materials with hydraulic gradients as low as one foot per mile or less, and if there is a flow at such low gradients, to ascertain if it follows Darcy's law which states that the flow of ground water through a given material varies directly as the hydraulic gradient.
(h) The results of the tests with the former apparatus are given in U. S. Geological Survey Water-Supply Paper 596 by N. D. Stearns. The new apparatus has just recently been started and no satisfactory results can yet be given out.
See Report I-1 for (b), (c), (g).

....

(27) (a) THIEM'S METHOD FOR DETERMINING PERMEABILITY OF WATER-BEARING MATERIALS.
(d) Under the supervision of L. K. Wenzel.
(e) L. K. Wenzel, U. S. Geological Survey, Washington, D. C.
(f) Pumping tests were conducted near Grand Island, Nebraska, during the summer of 1931, to attempt to determine the practicability of Thiem's method for determining permeability of water-bearing materials as a part of a cooperative investigation of the ground-water resources of the Platte Valley, Nebraska.
See Report I-1 for (b), (c) and part of (f)

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IOWA INSTITUTE OF HYDRAULIC RESEARCH.

(107) (a) HYDRAULIC TEST ON MODEL OF MISSISSIPPI RIVER BELOW KEOKUK DAM.
(b) U. S. Engineer Department, Rock Island District.
(c) Institute project.
(d) U. S. Engineer Department Staff.
(e) Martin E. Nelson, Associate Engineer.
(f) To determine remedy for diagonal currents below lock and effect of wing dams and old cofferdam on tail water of Keokuk plant.
(g) Investigation on model of river built to scale of 125 to 1.
(h) Progress report on first part completed, model recently extended to investigate second part of investigation.
(i) Will be completed July 1, 1933.

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(108) (a) HYDRAULIC INVESTIGATION OF GENERAL MODEL OF LOCK AND DAM NO. 4, MISSISSIPPI RIVER AT ALMA, WISCONSIN.
(b) U. S. Engineer Department, St. Paul District.
(c) Institute Project.
(d) U. S. Engineer Department Staff.
(e) Martin E. Nelson, Associate Engineer.
(f) To determine discharge and navigation conditions.
(g) Investigation on model of river to horizontal scale of 300 to 1 and vertical scale of 100 to 1.
(h) Cross sections ready for model construction.
(i) Will be completed in 1934.

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(109) (a) HYDRAULIC STUDIES TO IMPROVE INTAKE AND OUTLET CONDUITS FOR STANDARD LOCKS.
(b) U. S. Engineer Department, Upper Mississippi Valley Division.
(c) Institute Project and Graduate Thesis.
(d) U. S. Engineer Department Staff.
(e) Martin E. Nelson, Associate Engineer.
(f) To determine better design for emptying and filling of locks.
(g) Investigation on lock model on scale of 15 to 1 with many adjustable and variable features under control.
(h) Model under observation for three months.
(i) Investigation will continue for several years.

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(110) (a) HYDRAULIC STUDY OF MODEL OF LOCK AND DAM NO. 26, MISSISSIPPI RIVER AT ALTON, ILLINOIS.
(b) U. S. Engineer Department, Mississippi Valley Division.
(c) Institute project.
(d) U. S. Engineer Department Staff.
(e) Martin E. Nelson, Associate Engineer.
(f) To determine current effects and conditions downstream from proposed dam below mouth of Illinois River.

(g) Investigation conducted on model with movable bed with horizontal scale of 250 to 1 and vertical scale of 60 to 1.
(h) Model now under construction.
(i) Observations will begin about June 1.

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(111) (a) DEVELOPMENT OF "ROTOBRATOR" FOR CALIBRATION OF PITOT TUBES.
(b) U. S. Engineer Department.
(c) Institute project.
(d) U. S. Engineer Department Staff.
(e) Martin E. Nelson, Associate Engineer.
(f) Development of a rotating channel for the calibration of Pitot tubes.
(g) Apparatus with channel 10 feet in circumference has been developed to rate Pitot tubes which are held at fixed radius.
(h) Preliminary report available. Experiments on larger apparatus contemplated.

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(112) (a) FLOW OF WATER AROUND BENDS IN OPEN AND CLOSED CHANNELS.
(b) Bureau of Agricultural Engineering, U. S. Department of Agriculture.
(c) Institute project.
(d) U. S. Department of Agriculture Staff.
(e) David L. Yarnell, Senior Engineer.
(f) To determine losses, changes in pressure, velocity and direction of current flowing around both open and closed bends of various curvature and central angles.
(g) Investigation now being conducted with transparent pyralin pipe and bends 6 inch diameter standard curvature through angles of 90°, 180° and 270°.
(h) General study in progress since 1926; report completed on transparent conduits of square and rectangular section. Present set-up of 6-inch pyralin pipe under observation since March 1.

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(113) (a) CALIBRATION OF SILT MEASURING APPARATUS.
(b) Bureau of Agricultural Engineering, U. S. Department of Agriculture.
(c) Institute project.
(d) U. S. Department of Agriculture Staff.
(e) David L. Yarnell, Senior Engineer.
(f) To calibrate various devices for use in measuring the quantity of silt removed by surface runoff from agricultural lands.
(g) Investigations have been made on several types of apparatus.
(h) Separate reports prepared on devices tested.

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(114) (a) PILE TRESTLES AS CHANNEL OBSTRUCTIONS.
(b) Bureau of Agricultural Engineering, U. S. Department of Agriculture.

(c) Institute project.
(d) U. S. Department of Agriculture Staff.
(e) David L. Yarnell, Senior Engineer.
(f) To test head loss caused by pile trestles.
(g) Results of 1100 tests of full-size pile trestles and models of same.
(h) Report by Yarnell, Nagler and Woodward ready for publication.

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(115) (a) BRIDGE PIERS AS CHANNEL OBSTRUCTIONS.
(b) Bureau of Agricultural Engineering, U. S. Department of Agriculture.
(c) Institute project.
(d) U. S. Department of Agriculture Staff.
(e) David L. Yarnell, Senior Engineer.
(f) To measure obstruction and erosion caused by bridge piers of various shapes.
(g) Results of 2600 tests on larger pier operating under more extensive range of conditions than has hitherto been attempted.
(h) Report being edited for publication.

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(116) (a) RUNOFF STUDIES ON RALSTON CREEK.
(b) U. S. Department of Agriculture and University of Iowa.
(c) Institute Project.
(d) G. Marston and H. Evans.
(e) Floyd A. Nagler.
(f) To determine factors affecting runoff from small midwestern watersheds.
(g) Intensive study of runoff factors on 3 square mile water-shed near Iowa City, from which runoff is continuously measured by weir, rainfall at 8 stations including recording gage, and ground water observed at 18 points. Other studies include soil moisture, crops, etc.
(h) In continuous progress since 1924.

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(117) (a) TRANSPORTATION OF SEDIMENT BY FLOWING WATER.
(c) Graduate Theses.
(d) Chitty Ho, Roland A. Kampmeier.
(e) S. M. Woodward.
(f) To determine the relation of sediment movement to bottom and mean velocity.
(g) Experiments in glass walled flume upon movement of sediments of various size, shape and weight. Also revision of Gilbert's studies.
(h) To be completed in June, 1933.

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(118) (a) RELATION OF TAIL RACE FLOOR TO BOTTOM OF DRAFT TUBES.
(c) Graduate Thesis.
(d) A. Luksch.
(e) Floyd A. Nagler.
(f) To determine effect of location of tail race floor upon draft tube efficiency with and without spiral flow.
(g) Tests made on small model of vertical tube with movable flow plate, variable entrance vanes to induce helical flow of various angles. Photographic study of resulting stream lines by using transparent tube and tank with aluminum powder in circulation.
(h) To be completed July, 1933.

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(119) (a) STUDY OF MIXTURES OF STREAM FILAMENTS OF VARYING VELOCITY.
(c) Graduate thesis.
(d) J. S. Meyers.
(e) Floyd A. Nagler.
(f) To investigate phenomena of pressure recovery and loss in the alternation of velocity distribution in conduits.
(g) Study is being conducted in rectangular transparent conduit 3 inches x 6 inches x 40 feet long, in which divided currents of any amount and cross section may be introduced and observed until thorough mixture has resulted.
(h) First progress report will be completed July, 1933.

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(120) (a) FLOW IN BENDS OF QUARTER TURN DRAFT TUBES.
(c) Graduate thesis.
(d) C. A. Mockmore.
(e) Floyd A. Nagler.
(f) Study of flow phenomena with and without spiral discharge in types of 90° bends.
(g) Investigation being conducted in transparent pyralin bends of various shape, observing velocity distribution and losses.
(h) In progress since 1932; thesis report on bend of circular cross section available; present study will be completed in August, 1933.

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(121) (a) CHARACTERISTICS OF SIDE CONTRACTION METER.
(c) Graduate thesis.
(d) R. G. Poston and H. Evans.
(e) Floyd A. Nagler.
(f) Study of a Venturi meter formed by contracting only the sides of a circular pipe.
(g) Experiments upon pyralin meter in pipe 6 inches diameter and steel meter in pipe 4 feet in diameter determining constants, loss of head and throat pressure phenomena for various contraction ratios.

(h) Report on one 6 inch meter, 1 - 2 area contraction available. Investigation will be completed August, 1933.

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(122) (a) LATERAL SPREADING OF CONCENTRATED SPILLWAY DISCHARGE.
(c) Graduate thesis.
(d) Fred S. Witzigman.
(e) Floyd A. Nagler.
(f) Model study of type of sill which will effectively spread the flow of a narrow spillway over the entire width of the river.
(g) Experiments in small scale model designed sill that will accomplish lateral spreading of flow. Final tests on full scale spillway making velocity measurements of effectiveness of sill and apron.
(h) Report available June, 1933.

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(123) (a) DEVELOPMENT OF PITOT TUBE FOR USE IN MEASURING VELOCITY OF SEWAGE.
(c) Graduate thesis.
(d) Frank A. Kulas.
(e) Floyd A. Nagler.
(f) To develop a Pitot tube that will successfully measure the velocity of water carrying a large quantity of foreign matter that would clog the ordinary Pitot tube.
(g) A Pitot tube is being developed using high velocity jet that gives promise of successful use in dirty water.
(h) In progress. Completed August, 1933.

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(124) (a) CALIBRATION OF PADDLE WHEEL METER FOR SURFACE VELOCITIES.
(b) Chicago Sanitary District.
(c) Institute project.
(d) Frank A. Kulas.
(e) Floyd A. Nagler.
(f) To determine coefficients for paddle wheel type of current meter used by Chicago Sanitary District for measuring flow in large sewers.
(g) Paddle wheel meter floated in river canal and channels of various section and depth to determine discharge coefficients.
(h) Will be completed in 1934.

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(125) (a) STUDY OF PULSATIONS OF PIEZOMETERS.
(c) Graduate thesis.
(d) O. J. Baldwin, G. Shafer.
(e) Floyd A. Nagler.
(f) To determine causes, amplitude and period of pulsations in piezometer columns.
(g) Photographic records of pulsations in piezometers attached at

different points in a conduit are being studied to determine cause, effect of length of rubber hose, glass column, and methods of damping.
(h) Completed August, 1933.

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(126) (a) CALIBRATION OF SUBMERGED TRIANGULAR WEIR.
(b) Graduate thesis.
(d) R. E. Johnson.
(e) Floyd A. Nagler.
(f) To determine effect of submergence of flow through 90° triangular weir.
(h) Theoretical calculation of effect of submergence completed.

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(127) (a) CURTIS BEND IN IOWA RIVER.
(b) Graduate theses.
(d) R. L. Lancefield, F. L. Blue, J. K. Herbert.
(e) Floyd A. Nagler.
(f) To determine hydraulic phenomena in sharp 110° river bend near Iowa City.
(g) Measurements are being made of cross-section, velocity and current direction at five cross-sections, above, below and at the bend.
(h) Progress report to be made in July, 1933.

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LOUISIANA STATE UNIVERSITY AND AGRICULTURAL AND MECHANICAL COLLEGE.

(28) (a) HYDROLOGICAL STUDY OF CITY PARK LAKE DRAINAGE AREA.
(d) T. Smart and A. Lambert.
(e) Dr. Glen N. Cox, Associate Professor of Mechanics & Hydraulics.
(f) Study of rainfall, runoff, and evaporation.
(h) The gage house is under construction at the present time.
See Report I-1 for (b), (c), (g).

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

(29) (a) EXPERIMENTAL STUDY OF SEA WALL DESIGN.
(d) Professor K. C. Reynolds.
(e) Professor K. C. Reynolds.
(f) Improvement of sea wall design.
(g) Concrete basin 6 ft. x 20 ft. used with plunger for creating waves at one end. Models of several types of sea walls will be built at other end and be exposed to various wave conditions. Volume of sand and water passing over wall will be measured. Studies will be made of undermining, etc.
(h) Preliminary investigations of wave action on vertical walls begun. Paper entitled "Investigation of Wave Action on Sea Walls by the Use of Models" presented before the American Geophysical Union, April 28, 1933.
See Report I-1 for (b), (c).

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(30) EXPERIMENTAL INVESTIGATION OF THE TRANSPORTATION OF SAND BY RUNNING WATER,
(d) C. H. MacDougall of laboratory staff.
(e) C. H. MacDougall.
(f) To investigate the factors which influence the movement of sand and the attendant phenomena.
(h) Investigations practically completed. Paper entitled "Bed Sediment Transportation in Open Channels" presented before the American Geophysical Union, April 28, 1933. A comprehensive paper is in preparation.
See Report I-1 for (b), (c), (g).

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(31) (a) INVESTIGATION OF WAVE PHENOMENA IN CHANNELS.
(d) J. B. Drisko, of laboratory staff.
(e) J. B. Drisko.
(f) To determine characteristics of wave phenomena in channels. This includes tidal waves, waves of translation and flood waves.
(h) Various types of waves have been studied. Paper entitled "Wave Motion in a Channel" presented before the American Geophysical Union, April 28, 1933.
See Report I-1 for (b), (c), (g).

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(32) (a) DYNAMICS OF SUPPRESSED WEIR DISCHARGE.
(d) Hunter Rouse of laboratory staff.
(e) Hunter Rouse.
(f) To show relation between pressure distribution in nappe and (a) shape of nappe; (b) ratio of head on crest to depth of approach. To determine progression of contraction and velocity-of-approach coefficients as height of weir decreases to zero.
(h) Work complete for weir heights of 40 cm., 20 cm., 10 cm. At present a permanent floor is being built with a movable weir to provide the following weir heights: 5 cm., 2 1/2 cm., 1 1/4 cm., and 0 of the free overfall.
See Report I-1 for (b), (c), (g).

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(33) (a) EFFECT OF ANGULARITY AND DEPTH OF APPROACH ON SPILLWAY DISCHARGE.
(d) R. Eliassen and H. Farney.
(e) Professor K. C. Reynolds.
(f) To determine variation in spillway coefficient as angle of approach and depth of approach are varied.
(h) Angles of 30°, 60° and 90° investigated as a Master's thesis 1931-1932 by G. R. Lord and T. A. Fearnside. "An Experimental Investigation to Determine the Effect of Angularity and Depth of Approach on the Discharge over Spillways". Work completed. M. I. T. Master's thesis (1933) by Messrs. Eliassen and Faney entitled "An Experimental Investigation to Determine the Comparative Effect of Angularity and Depth of Approach on Flow over Vertical Sharp-crested Weirs and Spillways."
See Report I-1 for (b), (c), (g).

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(34) (a) EXPERIMENTAL INVESTIGATION OF THE HOLDING ABILITY OF ANCHORS.
(d) Lieut. R. K. James, U.S.N., and Lieut. W. E. Howard, U. S. N.
(e) Professor H. E. Rossell, Commander, U.S.N.
(f) To determine the variation in holding ability of an anchor as the angle of pull varies. To investigate the effect of changes in design.
(h) Experimental work completed. M.I.T. Master's thesis (1933) entitled "Investigation of Anchor Characteristics by Means of Models".

See Report I-1 for (b), (c), (g).

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(35) (a) EXPERIMENTAL STUDY OF FLOW OVER TYPICAL SPILLWAY SECTIONS.
(d) L. Reid.
(e) Professor K. C. Reynolds.
(f) To improve spillway design and put it on an analytical rather than empirical basis.
(h) Experimentation in progress.

See Report I-1 for (b), (c), (g).

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(36) (a) EXPERIMENTAL INVESTIGATION OF THE CAVITATION PHENOMENA.
(d) Hydraulic Machinery Laboratory, under direction of Professor Spannhake.
(e) Professor W. Spannhake, Professor of Hydraulics and Visiting Professor of Hydraulics from Technische Hochschule, Karlsruhe, Germany.
(f) An experimental study in a systematic way of the fundamental theory of cavitation and the pitting caused by cavitation.
(h) The unit is now complete in every detail, having connections to both a steam and a refrigeration unit for regulation of temperature, an air compressor for pressure regulation, and an analyzer to determine air content in the water. Many different profile shapes have been used and the pressure distribution measured along them. Motion pictures at a speed of 1000 per sec. have allowed a better study of the phenomena. Systematic endurance tests have been made in varying types of material under carefully regulated cavitation conditions, thus rating the ability of different materials to withstand the pitting effect. Work is in progress to determine the effect of the air content of the water upon cavitation pressures and pitting effects.

See Report I-1 for (b), (c), (g).

. . . .

(38) (a) LATERAL SPILLWAY CHANNELS.
(d) D. M. Stewart and H. W. Taul.
(e) Professor T. R. Camp.
(f) The purpose of these experimental studies is to determine the hydraulic conditions of flow in rectangular channels such as are used for the effluent flumes of settling tanks, to develop

the theory from the fundamental differential equations, and to correlate the theoretical results with experimental measurements.

(h) The work now being done is a continuation of the work started by Engler and LaPointe in 1930 and carried on by Hunter and Hough in 1932. M.I.T. thesis (1933) entitled "Experimental studies of the Hydraulics of Lateral Spillway Channels".

See Report I-1 for (b), (c), (g).

....

(40) (a) STUDY OF HYDRAULICS OF SEDIMENTATION BASINS.

(d) C. Chayabongse and S. D. Miller.

(e) Professor T. R. Camp.

(f) The purpose of this work is to develop as result of experimental measurements a rational theory for estimating the removal by sedimentation of suspended solids.

(h) The work now in progress is confined to the measurement of the distribution of velocities in a model settling tank, 2 feet wide, 1-1/2 ft. deep, and about 10 feet long. It is a continuation of thesis (1933) entitled "An Experimental Study of Velocity Distribution in a Model Settling Tank".

See Report I-1 for (b), (c), (g).

....

MICHIGAN STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE.

(128) (a) INVESTIGATION OF THE HEAT CONDUCTIVITY OF THE BOUNDARY FILM SURROUNDING HOT BODIES.

(b) Physics Department, Michigan State College.

(c) Graduate Thesis work for M.S. degree.

(d) William G. Keck.

(e) William G. Keck.

(f) To determine heat transfer from solids to gases, especially surface resistance. Air flow incidental to problem but proved to be a major problem.

(g) Air flow measured by hot wire anemometer with extreme accuracy.

(h) Complete, as far as air flow is concerned.

....

NATIONAL HYDRAULIC LABORATORY, BUREAU OF STANDARDS, WASHINGTON, D. C.

(42) (a) INVESTIGATION OF THE PHYSICS OF PLUMBING.

(d) R. B. Hunter.

(e) The Director, U. S. Bureau of Standards.

(f) To obtain data on which to base logical estimates of the capacities of various sizes of drain pipes, vertical and sloping, in plumbing systems.

(h) An installation of 6" pipe, which for a part of the work will be of glass, has been made for continuing the study, and several runs have been made.

See Report I-1 for (b), (c), (g), and part of (h).

....

(43) (a) INVESTIGATION OF PIPE BENDS.
(d) K. H. Beij, G. H. Keulegan.
(e) The Director, U. S. Bureau of Standards.
(f) To obtain the general laws of head loss in pipe bends; to correlate, insofar as possible, all available results of previous investigations; to obtain practicable formulas for use of engineers; and to extend the results to include flow of other fluids such as oils, steam, etc.
(h) The installation for tests on 4 inch steel tubing with commercial seamless bends has been set up, and necessary equipment is under construction.

See Report I-1 for (b), (c) and (g).

....

(44) (a) STUDY OF "DEEP WELL" CURRENT METERS.
(d) R. B. Hunter, W. F. Stutz.
(e) The Director, U. S. Bureau of Standards.
(f) To study the characteristics of current meters developed by the U. S. Geological Survey for explorations in artesian wells; to calibrate these meters in various sizes of well casings from 3" to 15" diameters; and to examine their reliability for detecting the location and extent of leaks in the casing.
(h) Tests have been run on two 3 inch meters and one 1.5 inch meter in a 3 inch pipe casing and on the 3 inch meter in 6 inch pipe casing. The latter included runs with the meter set at different distances from the center of the cross section of the 6 inch pipe and also runs in which leaks were produced artificially in the casing. Calibrations will be continued with larger casings.

See Report I-1 for (b), (c) and (g).

....

(129) (a) TRANSPORTATION OF SEDIMENT.
(b) U. S. Bureau of Reclamation.
(c) General research.
(d) C. A. Wright.
(e) The Director, U. S. Bureau of Standards.
(f) To determine the relative scouring action on a bed of fine sand of clear water and of water containing a considerable amount of fine silt.
(g) Details of the investigation not yet worked out.
(h) Equipment for this project being designed.

....

NEW YORK UNIVERSITY.

(130) (a) DURATION CURVES OF STREAM FLOW.
(c) General scientific research and in connection with theses for Master's degrees.

the theory from the fundamental differential equations, and to correlate the theoretical results with experimental measurements.

(h) The work now being done is a continuation of the work started by Engler and LaPointe in 1930 and carried on by Hunter and Hough in 1932. M.I.T. thesis (1933) entitled "Experimental studies of the Hydraulics of Lateral Spillway Channels".

See Report I-1 for (b), (c), (g).

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(40) (a) STUDY OF HYDRAULICS OF SEDIMENTATION BASINS.

(d) C. Chayabongse and S. D. Miller.

(e) Professor T. R. Camp.

(f) The purpose of this work is to develop as result of experimental measurements a rational theory for estimating the removal by sedimentation of suspended solids.

(h) The work now in progress is confined to the measurement of the distribution of velocities in a model settling tank, 2 feet wide, 1-1/2 ft. deep, and about 10 feet long. It is a continuation of thesis (1933) entitled "An Experimental Study of Velocity Distribution in a Model Settling Tank".

See Report I-1 for (b), (c), (g).

....

MICHIGAN STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE.

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(b) Physics Department, Michigan State College.

(c) Graduate Thesis work for M.S. degree.

(d) William G. Keck.

(e) William G. Keck.

(f) To determine heat transfer from solids to gases, especially surface resistance. Air flow incidental to problem but proved to be a major problem.

(g) Air flow measured by hot wire anemometer with extreme accuracy.

(h) Complete, as far as air flow is concerned.

....

NATIONAL HYDRAULIC LABORATORY, BUREAU OF STANDARDS, WASHINGTON, D. C.

(42) (a) INVESTIGATION OF THE PHYSICS OF PLUMBING.

(d) R. B. Hunter.

(e) The Director, U. S. Bureau of Standards.

(f) To obtain data on which to base logical estimates of the capacities of various sizes of drain pipes, vertical and sloping, in plumbing systems.

(h) An installation of 6" pipe, which for a part of the work will be of glass, has been made for continuing the study, and several runs have been made.

See Report I-1 for (b), (c), (g), and part of (h).

(43) (a) INVESTIGATION OF PIPE BENDS.
(d) K. H. Beij, G. H. Keulegan.
(e) The Director, U. S. Bureau of Standards.
(f) To obtain the general laws of head loss in pipe bends; to correlate, insofar as possible, all available results of previous investigations; to obtain practicable formulas for use of engineers; and to extend the results to include flow of other fluids such as oils, steam, etc.
(h) The installation for tests on 4 inch steel tubing with commercial seamless bends has been set up, and necessary equipment is under construction.
See Report I-1 for (b), (c) and (g).

....

(44) (a) STUDY OF "DEEP WELL" CURRENT METERS.
(d) R. B. Hunter, W. F. Stutz.
(e) The Director, U. S. Bureau of Standards.
(f) To study the characteristics of current meters developed by the U. S. Geological Survey for explorations in artesian wells; to calibrate these meters in various sizes of well casings from 3" to 15" diameters; and to examine their reliability for detecting the location and extent of leaks in the casing.
(h) Tests have been run on two 3 inch meters and one 1.5 inch meter in a 3 inch pipe casing and on the 3 inch meter in 6 inch pipe casing. The latter included runs with the meter set at different distances from the center of the cross section of the 6 inch pipe and also runs in which leaks were produced artificially in the casing. Calibrations will be continued with larger casings.
See Report I-1 for (b), (c) and (g).

....

(129) (a) TRANSPORTATION OF SEDIMENT.
(b) U. S. Bureau of Reclamation.
(c) General research.
(d) C. A. Wright.
(e) The Director, U. S. Bureau of Standards.
(f) To determine the relative scouring action on a bed of fine sand of clear water and of water containing a considerable amount of fine silt.
(g) Details of the investigation not yet worked out.
(h) Equipment for this project being designed.

....

NEW YORK UNIVERSITY.

(130) (a) DURATION CURVES OF STREAM FLOW.
(c) General scientific research and in connection with theses for Master's degrees.

(d) Thorndike Saville, graduate students, and assistants.
(e) Professor Thorndike Saville.
(f) To determine regional characteristics of stream flow and the applicability of statistical methods to its analysis.
(g) Construction of duration curves of weekly stream flow in terms of mean flow. Deviations of curves from one another as influenced by drainage area and regional characteristics and length of record. Construction of composite curve applicable to a region. Statistical analysis of curves and data.
(h) Study of five North Carolina streams completed and to be published: "Flow Duration Curves of North Carolina Streams" by Thorndike Saville and John D. Watson. Trans. American Geophysical Union, 1933. Studies in progress covering streams in New Jersey, New York, Tennessee, and North Carolina.
(i) The investigation is intended to cover the entire country, and the results will be presented in a series of papers dealing with different regions.

....

(131) (a) ESTIMATING FLOOD FLOWS.
(b) General scientific research and in connection with theses for Master's degrees.
(d) Thorndike Saville, graduate students, and assistants.
(e) Professor Thorndike Saville.
(f), (g) To compare all the various methods which have been proposed by applying them to streams having long records of flow, and to develop, if found desirable, improved methods.
(h) Comparison of several methods to 57 year daily record of Tennessee River in Master's thesis (1933) by H. Thielhelm. Results indicate marked diversity in results.

....

(132) (a) RAINFALL, RUNOFF, EVAPORATION, SILTING ON FLAT RIVER, N. C.
(b) N. C. Department of Conservation and Development and City of Durham, N. C.
(c) Project to improve operation of water supply and water power development of City of Durham, and as general research.
(d) Thorndike Saville and Charles E. Ray, Jr.
(e) Professor Thorndike Saville.
(f) To determine hydrological characteristics of Flat River drainage basin.
(g) Records collected from numerous stream flow and rainfall stations; floating evaporation pan and meteorological instruments. Measurement of silt deposits in reservoir. Forest and vegetation survey. Analysis of data collected.
(h) Records available since 1929. Preliminary report in 1931.

....

(133) (a) COASTAL EROSION IN NORTH CAROLINA.
(b) North Carolina Department of Conservation and Development and U. S. Beach Erosion Board.
(c) Research in conservation of natural resources.
(d) Thorndike Saville and Charles E. Ray, Jr.
(e) Professor Thorndike Saville.
(f) To determine nature and extent of coastal erosion at selected points and propose control measures.
(g) Historical study of coast from charts. Annual or more frequent surveys by land and air. Studies of sediments, currents, storms, etc. Plans for protecting beaches and inlets.
(h) Report on Wrightsville Beach, 1930. Report on Fort Fisher Beach by U. S. Beach Erosion Board, H. Doc. 204, 72nd Congress, 1st Session, 1931.

....

OHIO STATE UNIVERSITY, ROBINSON LABORATORY.

(134) (a) A DETERMINATION OF THE COEFFICIENTS OF COMMERCIAL METERING ELEMENTS FOR STEAM AND WATER.
(b) Ohio State Engineering Experiment Station and the Bailey Meter Company.
(c) General scientific research.
(d) S. R. Beitler and T. C. Barnes.
(e) S. R. Beitler.
(f) To determine the effect of temperature, viscosity, and expansibility of commercial metering elements (orifices, nozzles, and Venturi tubes.)
(g) Orifices, nozzles, and Venturi tubes for 3" and 6" lines were calibrated, using water and steam at various pressures and temperatures.
(h) The experimental work is completed but the results have not been completely analyzed. A partial report has been made in the paper to the A.S.M.E., "The Flow of Fluids Through Orifices in Six-inch Pipes" (Hyd. 52-7A-1929) and "A Study of Primary Metering Elements in Three-Inch Pipe." (R.P. 54-3, 1931.)

....

(135) (a) A STUDY OF THE FLOW OF WATER THROUGH ORIFICES IN VARIOUS SIZED PIPES.
(b) Ohio State Engineering Experiment Station, The American Gas Association, and the American Society of Mechanical Engineers.
(c) General scientific research.
(d) S. R. Beitler.
(e) S. R. Beitler.
(f) To determine the variation of orifice coefficients with pipe size and orifice size and to get comparative values for the various location of pressure taps at present used.

(g) Orifices have been calibrated in 1", 1-1/2", 2", 3", 6", 10", and 15" pipe lines using water as the calibrating fluid. Coefficients have been determined for the so-called corner taps, flange taps, Vena Contracta taps, pipe taps and throat taps for a wide range of orifice diameters, in all the pipe sizes.
(h) The projected experimental work is practically completed and partial reports were made to a joint sub-committee of the A.G.A., A.S.M.E., who are attempting to standardize orifice coefficients.

....

(136) (a) AN INVESTIGATION OF THE EFFECT OF FLANGE FORM ON ORIFICE COEFFICIENTS.
(b) Ohio State Engineering Experiment Station, The American Gas Association, and the American Society of Mechanical Engineers.
(c) General scientific research.
(d) S. R. Bietler, S. E. Overbeck.
(e) S. R. Beitler.
(f) To determine the effect of the various commercial orifice flanges now in use with the gas industry upon the coefficient of discharge of the orifice.
(g) Gas is measured passing through two orifices in series, one orifice being in a standard actting and the other clamped between various commercial cored flanges. The effect of the flange on the meter reading has been determined for both flange and pipe taps.
(h) Projected experimental work is practically completed.

....

PACIFIC HYDROLOGIC LABORATORY.

(45) (a) RELATION OF PERMEABILITY OF GRANULAR MATERIALS TO PARTICLE SIZE.
(b) Charles H. Lee.
(e) Charles H. Lee, Consulting Engineer, 58 Sutter Street, San Francisco, California.
(f) To provide a more accurate basis for preliminary classification of soil and earth materials as to permeability.
(h) No progress report.
See Report I-1 for (b), (c) and (g).

....

(46) (a) RELATION OF HEAD TO FLOW OF WATER THROUGH PARTIALLY SATURATED GRANULAR MATERIALS.
(d) Charles H. Lee.
(e) Charles H. Lee, Consulting Engineer, 58 Sutter Street, San Francisco, Cal.
(f) To ascertain more definitely the relation of flood flow in streams to seepage from their beds.
(h) No progress report.
See Report I-1 for (c) and (g).

....

THE PENNSYLVANIA STATE COLLEGE.

(137) (a) A STUDY OF VARIOUS TYPES AND KINDS OF STILLING DEVICES FOR USE IN CHANNELS OF APPROACH TO WEIRS AND FOR OTHER PURPOSES.
(b) The Pennsylvania State College.
(c) Research.
(d) Professors Elton D. Walker and H. K. Kistler.
(e) Either of above.
(f) The development of a standard stilling device, or possibly more than one device.
(g) Water is admitted to one end of a tank from a pipe, under such conditions as to produce a high velocity and considerable turbulence. The discharge is measured at the other end of the tank by means of a standard weir which has been calibrated. Velocity measurements are made at a number of points in a cross section about four feet downstream from the inlet both with and without any stilling devices in place. When stilling devices are tested, they are inserted about two feet below the inlet. Each device is tested with a number of different velocities, average velocities being determined by means of the weir readings and the cross section of the channel. We seek to relate the relative effectiveness of the various stilling devices to the magnitude and distribution of velocities in the cross section.
(h) It is hoped that a bulletin of the Pennsylvania State College may be issued sometime during the next calendar year giving the results of the work.

....

PRINCETON UNIVERSITY.

(138) (a) LOSS DUE TO SUDDEN ENLARGEMENTS IN OPEN CHANNELS.
(b) Scientific research.
(c) Graduate work for thesis and advanced degree.
(d) Lieut. J. A. Ostrand, Jr., U.S.A.
(e) Professor L. F. Moody.
(f), (g) To compare actual results with theoretical calculation following a rational method based on the impulse-reaction principle or "momentum" principle. Applied to flow in a glass flume of 12" x 12" section, with two ratios of sudden enlargement in addition to uniform section. Results show good agreement with theory.
(h) Work completed, Report nearing completion.

....

(139) (a) INVESTIGATION OF A "FREE" AND "DROWNED" HYDRAULIC JUMP. Or COMPARISON OF FREE JUMP WITH SUBMERGED DISCHARGE.
(b) Scientific research.
(c) Graduate work for thesis and advanced degree.
(d) Lieut. P. E. Ruestow, U.S.A.
(e) Professor L. F. Moody,

(f) (g) To compare actual results with theoretical calculation following a rational method based on the "momentum principle". Particularly directed to the "drowned" or partially submerged jump, or the transition stage between the complete or free jump and completely submerged discharge from an orifice. Applied to experiments in a 12" x 12" glass-sided flume about 8 ft. long. Results show good agreement with theory.

(h) Work completed, Report nearing completion.

....

(140) (a) INVESTIGATION OF RAINFALL AND RUNOFF IN CERTAIN WATERSHEDS.

(b) Scientific research.

(c) Graduate work for thesis and advanced degree.

(d) Lieut. G. Van B. Sawin, U.S.A.

(e) Professor L. F. Moody.

(f) An analytical and statistical investigation of typical eastern watersheds. A comparison of different methods of graphical analysis of runoff-duration curves, using "probability scales", or scales based on the probability integral. Also analysis of functional effect of certain variables on mean annual runoff.

(g) Analysis based on published records, (not experimental). Results have verified a theoretical conclusion that plotting duration curves on "probability paper" is a valuable method and that arithmetic scale of ordinates results in close approximation to a straight line for large discharges, and logarithmic ordinate scale has same result for small discharges; so that use of both scales gives a means of extrapolation and prediction at both ends of curve.

(h) Work nearing completion.

....

(141) (a) EFFECT OF TURBULENCE ON CURRENT METER MEASUREMENTS. AN INVESTIGATION.

(b) Scientific research.

(c) Graduate work for thesis and advanced degree.

(d) Lewis F. Moody, Jr.

(e) Professor L. F. Moody.

(f) To investigate experimentally the error due to turbulence in applying still-water ratings to moving water measurements. Comparison of actual results with calculations by the two-meter "angular" method, based on oblique still-water ratings, to determine whether this method is reliable with a particular kind and degree of turbulence.

(g) Lateral turbulence produced in rating flume by introducing lateral jets of water in plane of meters. Four Ott meters tested: two of "spoke" or "paddle" type (right and left hand meters), and two of "screw" type (right and left hand).

(h) Work completed. Report nearly complete.

(i) Results do not confirm the conclusions by the "angular calibration" method.

....

(142) (a) EFFECT OF LONGITUDINAL VELOCITY OSCILLATIONS ON CURRENT METER PERFORMANCE.
(b) Scientific research.
(c) Graduate work for thesis and advanced degree.
(d) Robert S. Hackett.
(e) Professor L. F. Moody.
(f) To determine whether, or to what degree, variations or pulsations in the magnitude of velocity affect the recording of a current meter. Involves the effect of that factor in ordinary flowing water which results in variation of magnitude of velocity, as a result of turbulence or eddies, as separated from variations in direction or angularity.
(g) Four meters investigated, Ott meters, two (right and left-hand) of "spoke" or "paddle" type, and two (right and left-hand) of "screw" type. Meters suspended on rod mounted on horizontal axis on rating car, so that meters are oscillated in direction of motion during a still-water rating in the rating flume. Oscillation produced mechanically.
(h) Work nearing completion.
(i) Meters are all of type having helical generating lines in the blade surfaces. Results show that longitudinal velocity variations of uniform character have no measurable effect on the meter performance, within limits of accuracy of measurement.

....

(143) (a) INVESTIGATION OF TRIANGULAR WEIRS OF VARIOUS VERTEX ANGLES.
(b) Scientific research.
(c) Graduate work for thesis and advanced degree.
(d) John Campbell, Jr.
(e) Professor L. F. Moody.
(f) Continuation of program of previous years, extending measurements from 90° to 30° vertex angle, and covering a coordination and partial formulation of results.
(g) Weirs calibrated by volumetric measurement of discharge. Deflecting chute used with a calibrated tank receiving the discharge. Coefficients determined and plotted, and variation of coefficients with head and angle investigated as to functional characteristics.
(h) Work nearing completion as to one stage of program.
(i) Some attention given to dimensional analysis of problem considering effects of viscous and capillary forces (surface tension.)

....

PURDUE UNIVERSITY.

(47) (a) FLOW OF FLUIDS THROUGH CIRCULAR ORIFICES.

(d) F. W. Greve and graduate students. (e) Prof. F. W. Greve.

(f) To determine experimentally the effects of density, surface tension, viscosity, and temperature upon the rate of discharge through small circular orifices.

(g) The liquids under investigation were water, three sucrose solutions of different densities, furnace oil, engine oil, and a mixture of furnace and engine oil. Flow was maintained by a small pumping unit discharging directly into an open orifice tank that was approximately 15 in. in its three dimensions. The nominal diameters of the thin-edge orifices, cut in 1/4-in. brass plates, were 1/4, 3/8, 1/2, 5/8, 3/4, and 7/8 in. respectively. The discharge from each orifice was directed into either a weighing tank or into the reservoir which supplied the pump. The discharge was weighed to within one ounce. A telescope and micrometer scale attached to a piezometer of 2 in. diameter permitted readings of the head to be noted to within 1/1000 in. Time was indicated on a stop-watch. The tests were made at room temperature. An Engler viscometer, a Cenco-De Novay tensiometer, and a Jolly balance were employed to measure the respective viscosities, surface tensions, and densities.

(h) Progress: The investigation has been completed with the present equipment of small capacity. The results should be considered in the nature of indications rather than conclusions, because of limited range in head and temperature. Results: 1. For a given ratio of head to diameter, the discharge coefficient decreases with increase in diameter except for very viscous fluids. 2. The effect of viscosity and other fluid properties upon the discharge coefficient increases with decrease in diameter. 3. The discharge coefficient may either increase or decrease with increase in head, depending upon the fluid. 4. For fluids of high viscosity, the discharge coefficient increases with increase in head and decreases with further increase in viscosity. 5. For low-viscosity fluids the discharge coefficient decreases with increase in head and increases with increase in density. 6. The density is the predominant influence upon the discharge coefficient for liquids of low viscosity; the reverse is true for liquids of high viscosity. The line of demarcation between these two factors is not well defined. 7. Insufficient data were available to determine the effect of surface tension upon the discharge coefficient.

(i) Plans are in preparation to extend the investigation with enlarged equipment and temperature control.

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STANFORD UNIVERSITY, SCHOOL OF ENGINEERING.

(144) (a) DETERMINATION OF THE COEFFICIENTS FOR DISCHARGE OVER MODELS OF SOME DAM CRESTS NOW IN USE ON THE WESTERN RIVERS OF THE UNITED STATES OF AMERICA.
(b) Self.
(c) Investigation for thesis for the advanced degree of Engineer in Civil Engineering.
(d) Allan J. Meadowcroft and Niel F. Meadowcroft.
(e) A. J. Meadowcroft.
(f) See title.
(g) Tests on models of various scales and crest lengths in channels of different widths.
(h) The observations have been completed, analysis of results is in progress, and the report or thesis is expected to be completed next month.
(i) The investigation appears to have progressed to the satisfaction of all concerned.

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STEVENS INSTITUTE OF TECHNOLOGY.

(145) (a) GEOMETRICALLY SIMILAR SHIP MODELS IN MIXED FLOW.
(c) Graduate thesis for advanced degree.
(d) Albert Shields.
(e) Professor Kenneth Davidson.
(f) Effects of model size in the region of Reynold's numbers in which transition from laminar to turbulent flow occurs. Effects on boundary layer and eddy formation.
(g) Towing three geometrically similar models of special form.
(h) Completed June 1, 1933.

....

(146) (a) CORRELATION BETWEEN SMALL MODEL RESISTANCE AND RESISTANCE OF FULL SIZE RACING SAILING YACHT.
(c) General scientific research.
(d) Professor Kenneth Davidson.
(e) Professor Kenneth Davidson.
(f) A check on the variations of skin friction, wave-making and eddy making with change in size between full size and a model ordinarily running in the transition region.
(g) Towing of full size yacht and small scale model.
(h) Preliminary testing of both sizes completed and correlation under way.

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TEXAS ENGINEERING EXPERIMENT STATION.

(147) (a) THE LOSS OF HEAD IN CAST IRON TEES.
(b) Texas Engineering Experiment Station in cooperation with the Research Laboratory of the American Society of Heating and Ventilating Wngineers.

(c) General scientific research.
(d) F. E. Giesecke, W. H. Badgett, and J. R. D. Eddy.
(e) The Director, Texas Engineering Experiment Station, A. and M. College of Texas, College Station, Texas.
(f) To determine a means of calculating the loss of head for the flow of water through cast iron tees.
(g) The investigation included all possible combinations of flow in 3/4 in., 1-in., and 1-1/2-in. standard cast iron tees, and for one combination of flow in 1-1/2 x 1-1/4 x 1-in. standard cast iron tees with water for all the tests at 70°F. and under a constant head. The percentage of water flowing through the outlets of the tee under investigation was controlled by gate valves and the discharge was measured by the volumetric method. Pressure drops were measured by piezometer rings and water column manometers.
(h) The work as described above has been completed and published as Bulletin 41 of the Texas Engineering Experiment Station.
(i) It is planned to continue the investigation of the loss of head in tees in the near future to include other sizes of tees, particularly the larger sizes, and tees with different sizes of outlets, as 2 x 1-1/2 x 1-in. tees. The effect of temperature will also be studied.

....

U. S. BUREAU OF RECLAMATION.

(48) (a) HYDRAULIC MODEL EXPERIMENTS FOR THE DESIGN OF BOULDER DAM.
(d) Research Division, U. S. Bureau of Reclamation.
(e) U. S. Bureau of Reclamation, Denver, Colorado.
(f) These experiments are being carried out for the design of the spillways, gate towers, penstocks and needle valve outlets at Boulder Dam.
(h) The experimental work and preparation of the report on these studies is still under way, and will continue for some time. When the results of these studies are in shape for giving to the public, it is expected that technical reports for general distribution will be issued.

See Report I-1 for (b), (c) and (g)

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U. S. WATERWAYS EXPERIMENT STATION.

(51) (a) SEDIMENT INVESTIGATIONS.
(b) Mississippi River and Tributaries.
(c) All experiments are prosecuted to the end of aiding in the development of plans for flood control, harbor improvement, navigation, etc. All have a direct practical application to the work of the Corps of Engineers, U. S. Army, in its administration of the Rivers and Harbors of the Nation. The U. S. Waterways Experiment Station holds as an unvarying principle

the maintenance of the closest contact with the field in all experimental work. This contact is kept both by Station personnel visiting the prototype and by engineers from the field visiting the Station while any particular model study is in progress.

(d) All experiments are conducted at the U. S. Waterways Experiment Station, by personnel of the Station under the direction of Lt. H. D. Vogel, Director of the Station. Further information and data covering any particular experiment may be obtained from the Director, U. S. Waterways Experiment Station.

(e) Movement of sedimentary material through Mississippi River system - silting of reservoirs.

(f) Field and laboratory investigations, analysis of samples, compilation of curves.

(g) Studies for 1930-31 reported on; other studies still in progress.

....

(52) (a) SOILS INVESTIGATIONS.

(b) Navigable Waterways, U.S.A.

(c) and (d) See (51).

(e) Physical analyses of soils, samples, for levees, hydraulic fills, etc.

(f) All kinds of mechanical analyses.

(g) Studies in progress continually.

....

(59) (a) LEVEE SEEPAGE.

(b) Mississippi river commission.

(c) and (d) See (51).

(e) Locate hydraulic gradient and seepage lines in levees of standard section and of varying materials.

(f) Loop of levees, standard section, 10 feet high, of various materials and placed in various ways, kept full; measurements taken.

(g) Loop levee built, observations now in progress.

....

(70) (a) RALEIGH BAR.

(b) District Engineer, Louisville, Ky.

(c) and (d) See (51).

(e) Development system to improve navigability of Raleigh Bar (and other bars) Ohio River.

(f) Model scales of 1 to 720 and 1 to 72, with movable bed.

(g) Completed.

....

(74) (a) TRACTIVE FORCE.

(b) Mississippi River Commission.

(c) and (d) See (51).

(e) Critical depths and slopes to cause movement of any given bed load.

(f) Flume tests in special tilting flume.

(g) In progress.

....

(77) (a) ISLAND NO. 35, MISSISSIPPI RIVER. *
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Develop methods of improving navigation.
(f) Model scale 1 to 600 and 1 to 150, movable bed.
(g) Nearing completion.
* Report I-1 reads "Island No. 55". 35 is correct.

....

(80) (a) HOTCHKISS BEND, MISSISSIPPI RIVER.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Develop dikes upstream to improve navigation conditions.
(f) Model scales 1 to 600 and 1 to 150; movable bed.
(g) In progress.

....

(81) (a) ST. CLAIR RIVER COMPENSATING WEIRS.
(b) Great Lakes Division.
(c) and (d) See (51).
(e) Determine kind, number and placing of weirs to raise level of Lake Huron.
(f) Model scales 1 to 100 undistorted and 1 to 100 against 1 to 30, also flume tests of individual weirs.
(g) In progress.

....

(83) (a) FORT CHARTRES, MISSISSIPPI RIVER.
(b) District Engineer, St. Louis, Mo.
(c) and (d) See (51).
(e) Develop dike system to improve depths over crossings.
(f) Model scales 1 to 1000 and 1 to 100; movable bed.
(g) In progress.

....

(84) (a) BROOKS POINT, MISSISSIPPI RIVER.
(b) District Engineer, St. Louis, Mo.
(c) and (d) See (51).
(e) Develop dike system to improve depths over crossings.
(f) Model scales 1 to 1000 and 1 to 100; movable bed.
(g) In progress.

....

(85) (a) ACTION OF BED LOAD AT A STREAM FORK.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Characteristics of a Bifurcated Flume.
(f) Flumes with divided channels movable beds.
(g) 1st and 2nd phases complete, more to come.

....

(87) (a) BRAZOS SANTIAGO PASS, GULF OF MEXICO.
(b) Gulf of Mexico Division.
(c) and (d) See (51).
(e) Effects of jetties on present channel.
(f) Model scales 1 to 300 and 1 to 150.
(g) In progress.

....

(88) (a) FITLER BEND MISSISSIPPI RIVER.
(b) Mississippi River Commission.
(c) and (d) See(51).
(e) Effects of Point Bar dredging.
(f) Model scales 1 to 800 and 1 to 125; movable bed.
(g) In progress.

....

(90) (a)POINT PLEASANT MISSISSIPPI RIVER. *
(b)Mississippi River Commission.
(c) and (d) See (51).
(e) Develop dike system to improve conditions for navigation.
(f) Model scale 1 to 1000 and 1 to 100; movable bed.
(g) In progress.

* Report I-1 reads "Toney's Towhead".
Title above is correct.

....

(91) (a) MILLIKENS AND PAW PAW BEND MISSISSIPPI RIVER.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Cut-offs divisions, and other problems, Mississippi River from Mile 560 to Mile 650.
(f) Model scales 1 to 1000 and 1 to 100; movable bed.
(g) In progress.

....

(92) (a) GLASSCOCK BEND, MISSISSIPPI RIVER.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Same for Mississippi River from Mile 650 to Mile 740.
(f) Model scales 1 to 1000 and 1 to 100; movable bed.
(g) In progress.

....

(93) (a) LAKE LONG BIFURCATION, ATCHAFALAYA RIVER.
(b) Mississippi River Commission.
(c) Study of bed load movement at this stream fork, and study of dredge cut above.
(d) See (51).
(e) Study of bed load movement at this stream fork.
(f) Model scales 1 to 500 and 1 to 50; movable bed.
(g) In progress.

....

(141) (a) WINYAH BAY, SOUTH CAROLINA COAST.
(b) Division Engineer, South Atlantic Division.
(c) and (d) See (51).
(e) Study of means of increasing navigable depths in the harbor.
(f) Model scales 1 to 500 and 1 to 100, tidal study.
(g) In progress.

....

(142) (a) COW ISLAND CUT-OFF, ATCHAFALAYA RIVER.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Study of bed load and current direction after this Cut-off is effected.
(f) Model scales 1 to 400 and 1 to 75.
(g) In progress.

....

(143) (a) ISLAND NO. 20, MISSISSIPPI RIVER.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Study of effects of regulating works on channel location and depths.
(f) Model scales 1 to 1000 and 1 to 125, movable bed.
(g) In progress.

....

(144) (a) ATCHAFALAYA RIVER BASIN.
(b) Mississippi River Commission.
(c) and (d) See (51).
(e) Study of the effects of changes in the regimen of the effluents of the Atchafalaya.
(f) Model scales 1 to 1500 and 1 to 100; fixed bed.
(g) In progress.

....

(145) (a) ROBINSON CRUSOE ISLAND, MISSISSIPPI RIVER.
(b) District Engineer, Memphis, Tenn.
(c) and (d) See (51).
(e) Study of proposed regulating works.
(f) Model scales 1 to 1000 and 1 to 125; movable bed.
(g) In progress.

....

(146) (a) ARTICULATED CONCRETE MATTRESS STUDY.
(b) District Engineer, Memphis, Tenn.
(c) and (d) See (51).
(e) Study of the causes of leaching of subsoil from under concrete materials.
(f) Full scale; small scale models supplementing.
(g) In progress.

....

UNIVERSITY OF MINNESOTA.

(94) (a) TRANSPORTATION OF SEDIMENT.
(c) Prof. Lorenz G. Straub.
(f) Investigations of the transportation of bed sediment in alluvial rivers and the effect of contraction works on the river channel.
(g) In progress.

....

(95) (a) BROAD-CRESTED WEIRS.
(c) Prof. Lorenz G. Straub.
(f) Characteristics of broad-crested weirs, experimentally establishing the pressure-momentum relations.
(h) In progress.

....

(96) (a) EXPERIMENTAL DESIGN OF DROP-CULVERT SPILLWAYS.
(c) Prof. Lorenz G. Straub.
(h) In progress.

....

(97) (a) MODEL TESTS OF SAND DAMS.
(c) Prof. Lorenz G. Straub.
(h) In progress.

....

(98) (a) PERMEABILITY OF GRANULAR MATERIALS.
(c) Prof. Lorenz G. Straub.
(f) Investigation of the permeability of granular materials when subjected to high liquid pressures.
(h) In progress.

....

(99) (a) LAWS OF HYDRAULIC SIMILITUDE.
(c) Prof. Lorenz G. Straub.
(f) Investigation of the limitations of the laws of hydraulic similitude.
(h) In progress.

....

UNIVERSITY OF WISCONSIN.

(147) (a) EXPERIMENTAL STUDY OF THE HYDRAULICS AND PNEUMATICS OF THE PLUMBING SYSTEM.
(b) Laboratory project.
(d) F. M. Dawson, L. H. Kessler, H. Ruf, H. Pommerenck, S.E.Kotz.

(f) To determine by experimental study and show by apparatus the following features:
   (1) Friction loss in small house water supply installations, including losses in copper, lead, iron pipes, valves, water meters, and in hot and cold water fixtures.
   (2) Water hammer developed in piping layouts and methods of relief of this pressure in the plumbing water supply system.
   (3) Proper venting of vertical stacks and horizontal waste and soil pipes.
   (4) Self-siphonage of various types of traps.
   (5) Heating of hot water by oil and gas and increase of pressure due to expansion of water and best method of control of this pressure.
   (6) Construction of brazed, wiped, and soldered joints in copper and lead piping, and strength of these joints.
   (7) Adequate water supply to a battery of closets operated by flushometer valves.
   (8) Chemical solvents for cleaning of stoppages in waste pipes.
   (9) Experimental investigation of grease traps.

(h) Most of the work was completed in June, 1933.

....

(148) (a) STUDY OF FLOW OVER TRIANGULAR OR V-NOTCH WEIRS.
(b) Laboratory project.
(c) F. M. Dawson and A. T. Lenz.
(f) To collect data already published and make new tests on the triangular weir for the purpose of producing working tables for triangular weirs good for any viscosity and angle of notch.
(h) Material collected and studies made. Should be ready for publication within a year.

....

(149) (a) DISCHARGE OVER WEIRS IN SIDE OF CHANNEL.
(b) Laboratory project.
(f) To determine the discharge over a rectangular weir which is placed in the side of a flowing channel.

....

(150) (a) DISCHARGE THROUGH ORIFICES ON END OF PIPE LINE.
(b) Laboratory project.
(f) To determine the coefficient of discharge for orifice openings having various ratios of area to that of approach pipe. Velocity of approach and partial suppression of contraction affects discharge from these orifices.

....

(151) (a) RESISTANCE TO FLOW THROUGH LOCOMOTIVE WATER HYDRANTS AND RELIEF FROM WATER HAMMER PRESSURES DUE TO THE CLOSURE OF CYLINDRICAL VALVES.
(b) Laboratory project.
(d) L. H. Kessler.
(f) To determine the loss of head in valve, riser in spout of locomotive water column, and study relief valves, and regulation of valve travel and the effects on the control of water hammer pressures within limits that are not destructive to water service installations.

....

WEST VIRGINIA UNIVERSITY.

(49) (a) SEDIMENTATION OF SMALL PARTICLES SUSPENDED IN WATER.
(b) West Virginia University.
(c) Graduate work.
(d) H. W. Speiden and L. V. Carpenter.
(e) L. V. Carpenter, College of Engineering, West Virginia University, Morgantown, W. Va.
(f) To study the laws governing the rate of settling of small particles in model basins.
(h) Experimental work has been started on a basin 4 ft. by 6 ft. in cross section and 10 ft. long. Other basins will be constructed in the near future.
See Report I-1 for (g).

....

(50) (a) DISCHARGE THROUGH THIN PLATE ORIFICES IN PIPE LINES.
(d) L. V. Carpenter, assisted by students.
(e) L. V. Carpenter, College of Engineering, West Virginia University, Morgantown, W. Va.
(f) To study coefficients of various sizes of circular thin plate orifices in pipe lines with a view to the determination of the relations existing between the coefficients of large and small orifices by principles of similarity.
(h) Experiments on the 2-inch pipe lines are completed, and preparations are being made to start experimental work on the 3-inch pipe line.

See Report I-1 for (b), (c) and (g).

....

COMPLETED PROJECTS.
Abstracts and References.

UNIVERSITY OF CALIFORNIA.

(11) "Hydraulic Model Test of Lake Washington Ship Canal", by Frank E. Fries and Alvin G. Viney.

Summary.

Purpose: This experiment was undertaken with two purposes in mind: first, to determine, by means of model experiments, a more satisfactory means of preventing the contamination of the fresh water basin at Seattle; and second, to observe the effects of variation of the density of the salt solution on the velocities and distances of travel of the salt water wave, the variation of density being the equivalent of varying the lift of a lock, its dimensions otherwise remaining the same.

Apparatus: The apparatus used in the experiment consisted of an accurate model, constructed of concrete to scales of 1 to 480 horizontally and 1 to 108 vertically, of approximately 12,000 feet of the Lake Washington Ship Canal, starting some 800 feet below the locks and extending upstream towards Lake Union.

Auxiliary apparatus consisted of a tank for storing salt water, point gages, a Westphal balance, a glass pipette, and stop watches.

Procedure: The procedure was as follows: 1. A volumetric calibration of the model was obtained. 2. The average daily number of equivalent large lockages was computed and found to be approximately 17. This number was then used as the number of lockages per run on the model. 3. Each lockage was made by running the prepared salt solution directly into the lock chamber to the proper depth and then quickly removing the gate. 4. The progress of the wave out of the lock and up the channel was carefully observed and the times required for the wave front to reach certain sections noted with stop watches and recorded. 5. After 1, 10, and 17 lockages, locking was stopped while samples were taken with the pipette at various depths in the center of the channel at each of several sections. These were checked by means of the Westphal balance and their specific gravities recorded. On several occasions, a delay of one or two days occurred before sampling was done after 17 lockages to see if there was a noticeable effect due to diffusion. 6. Baffles, retaining sills, and sumps were inserted in the channel in order to determine means of preventing the contamination of the fresh water basin.

After these experiments had been made, the following curves were drawn from the data observed: 1. Average velocity to end point against distance in feet, 2. Rate of decrease of velocity against model characteristic, 3. Percent specific gravity against depth, 4. Dilution against number of lockages, 5. Salinity distance against number of lockages, 6. Volume against depth.

Theory: See the following references:
Report on Salt Water Barrier for Sacramento and San Joaquin Rivers, California. By Walker R. Young, U. S. Bureau of Reclamation.

Model Law for Motion of Salt Water Through Fresh.
By M. P. O'Brien and John Cherno, A.S.C.E. Proceedings, December, 1932.
Annual Report Isthmian Canal Commission, 1914.
Salt Contamination at the Panama Canal. By Kirkpatrick, Engineering News Record, Vol. 92, 1924, Page 935.
Salinity of Lake Washington Ship Canal. By E. V. Smith and T. S. Thompson, Engineering Experimental Bulletin No. 41, University of Washington, May 1, 1927.
Lake Washington Ship Canal. By Col. W. J. Barden, C.E. and A. W. Sargent, Transactions A.S.C.E., Vol. 92, 1928, Paper No. 1679.
Predetermining the Extent of a Sewage Field in Sea Water. By A. M. Rawn and H. K. Palmer, Transactions A.S.C.E., Vol. 94, 1930, Paper No. 1750.

Results: These experiments showed very definitely that: 1. The velocity and distance of the salt wave increased as the specific gravity of the salt water increased. 2. That salt penetrates far up a channel from a lock when no means of trapping and flushing are provided, and that the amount of contamination increases with the depth, and that continued locking under these conditions causes this contamination to gradually approach the surface of the fresh water basin. 3. That the present means of trapping and flushing at the Lake Washington Ship Canal does not completely control the salt flow. 4. That completely effective means of controlling the salt flow and preventing contamination can be obtained. Three such means were determined.

....

(24) "Trajectory of the Nappe of a Rectangular Sharp-crested Weir Without End Contractions." O'Shaughnessy and Petersen. (Thesis may be borrowed from Director of Laboratory.)

Summary.

Purpose: To study the trajectory of the nappe of a rectangular sharp-crested weir having free overfall and no end contractions, and to obtain, if possible, a mathematical expression for this trajectory.
Procedure: Water was allowed to flow over the crest of the weir and fall freely for a vertical distance of about fifteen feet. The profile of the nappe was then observed by two devices. In the region of the crest, (down to about one foot below the crest), the upper surface was measured with a descending point gage. The under surface was not measured in this vicinity. The rest of the nappe, lying below the range of the point gage, was measured by sighting at the profile from the side with a peep sight whose coordinates in space (with respect to the weir crest) could be observed.

The height of the weir was varied from one indh to nine inches at two inch intervals. For each height of weir the head (at 5.0 ft. from weir crest) was varied from about 0.05 ft. to 0.40 ft. by adding increments of about 0.05 ft. In all, thirty-nine different nappes were measured.

The nappes for each height of weir were reduced to correspond to a head of one foot on the weir (by dividing all coordinates for each head by that head) and plotted together on millimeter paper to a scale of 25 mm. = 1 ft. Through the average of these points a profile was drawn and its center-line carefully plotted.

Findings: It was discovered that these center-lines (one for each height of weir), could be expressed by an equation of the form $x = k(y - c)^n$, where "x" and "y" are coordinates referred to the weir crest, "k" is a constant very near 1.50, "c" is a constant having a value between 0.40 and 0.60, and "n" is a constant between 0.500 and 0.525. Two sets of equations were obtained: Set One.

Height of weir.	Equation.
3 ins.	$x = 1.48(y + 0.53)^{0.521}$
5 ins.	$x = 1.51(y + 0.53)^{0.508}$
7 ins.	$x = 1.44(y + 0.53)^{0.517}$
9 ins.	$x = 1.50(y + 0.53)^{0.506}$
Mean for all heights	$x = 1.505(y + 0.53)^{0.506}$

This formula gave results whose maximum difference from the plotted curves was 4.0% (from y = 0.0 to y = 35.0 ft.)

Set Two

Height of weir.	Equation.
3 ins.	$x = 1.50(y + 0.50)^{0.513}$
5 ins.	$x = 1.50(y + 0.50)^{0.510}$
7 ins.	$x = 1.50(y + 0.50)^{0.504}$
9 ins.	$x = 1.50(y + 0.50)^{0.508}$
Mean for all heights.	$x = 1.50(y + 0.50)^{0.508}$

The maximum error with this mean formula (between limits y = 0.0 and y = 35.0) was 3.0%.

It will be noticed that in Set 2, the exponent only was varied. The other constants were selected in an endeavor to simplify the formulae of Set 1.

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U. S. WATERWAYS EXPERIMENT STATION.

(51) "Sediment Investigations on the Mississippi River and its Tributaries Prior to 1930". Paper H, July, 1930. (Out of print).
"Sediment Investigations on the Mississippi River and its Tributaries 1930-1931. December, 1931. (Price 75 cents.) (Paper U.)
(53) "Bonnet Carre Floodway". (No reference or abstract furnished.)
(54) "Cut-offs Greenville Bends". (No reference or abstract furnished.)
(55) "Experiment to Determine the Limit of Backwater Influence in the Illinois River". Paper Y, February, 1931. (Price 10 cents.)

(56) "Model Study of Effects of Operating Birds Point-New Madrid Floodway", Paper C, December, 1932. (Price 35 cents.)
(57) "Hydraulic Studies of Proposed Dam No. 37, Ohio River", Paper D, May, 1931. (Price 25 cents.)
(58) Relief Map Alluvial Valley, Mississippi River. (No reference or abstract furnished.
(60) "Experiment to Determine the Effects of Proposed/Dredged Cut-offs in the Mississippi River", Paper I, April 15, 1932. (Price 50 cents.)
(61) Brunswick Levee Extension. (No reference or abstract furnished.)
(62) "Model Study of Effects of Dikes on the River Bed at Walkers Bar, Ohio River", Paper L, January, 1932. (Price 35 cents.)
(63) Boeuf Floodway. (No reference or abstract furnished.)
(64) Pipe Bends. (No reference or abstract furnished.)
(65) Harbors Front Levees. (No reference or abstract furnished.)
(66) Drainage Spillways. (No reference or abstract furnished.)
(67) "Experiment to Determine the Effects of Mississippi River Backwater on the Red River". Paper 10, January, 1933, (Price 15 cents.)
(68) "Experiments to Determine the Erosive Effects of Floodwaters on Railroad Embankments", Paper R, May, 1931. (Price 15 cents.)
(69) Morrison Towhead. (No reference or abstracts furnished.)
(71) Stewarts Bar. (No reference or abstract furnished.)
(72) Diamond Point Cut-off. (No reference or abstract furnished.)
(73) Concrete and Gravel Revetments. (No reference or abstract furnished.)
(75) Island No. 9, Mississippi River. (No reference or abstract furnished.)
(76) Starved Rock Lock and Dam. (No reference or abstract furnished.)
(78) Laconia Bend, Mississippi River. (No reference or abstract furnished.)
(79) Race Track Towhead. (No reference or abstract furnished.)
(82) Bed Load Diversion. (No reference or abstract furnished.)
(86) St. Andrews Bay, Gulf of Mexico. (No reference or abstract furnished.)
(89) Relief Map, Bird's Point-New Madrid Floodway. (No reference or abstract furnished.)

Note: Reports for which prices are quoted may be obtained by writing the President, Mississippi River Commission, Vicksburg, Miss., inclosing the proper amount.

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ABSTRACT OF PROGRESS REPORT ON CAVITATION RESEARCH
BY SAFE HARBOR WATER POWER CORPORATION.*

By Carroll F. Merriam,
Pennsylvania Water & Power Company, Baltimore, Md.

The Bureau of Standards has received a planographed copy of a Progress Report on Cavitation Research conducted by Prof. Wilhelm Spannhake, Visiting Professor of Hydraulics at the Massachusetts Institute of Technology for the Safe Harbor Water Power Corporation. This report was based upon a paper presented at a meeting of the Hydraulic Power Committee, New England Electric Utilities Engineers, Hotel Statler, Boston, Mass., on March 3rd, 1933. A limited number of copies are available and may be had on application to Mr. Carroll F. Merriam, Safe Harbor Water Power Corporation, Lexington Building, Baltimore, Maryland.

The report itself deals only with the progress made to March 24th, but has been supplemented by letter announcing further accomplishment and outlining work in progress. This abstract will, therefore, condense both the printed report and the subsequent information.

Increasing interest has been shown in the subject of cavitation, particularly because the introduction of the propeller type water wheel makes this problem far more acute. It had been recognized even with Francis wheels that there are two controlling factors which greatly influence the damage caused by pitting. One of these is the height of setting of the wheel above tailwater elevation, and the other is specific speed.

Among the pioneers in this field is Dr. Thoma of Munich, who as a visiting professor at M.I.T. gave several lectures explaining the work which he had done abroad. At that time an attempt was made on the part of farsighted individuals to establish a cavitation laboratory for further study in this country. Unfortunately this plan was not carried out on a national scale.

It had been noted that if the head on a turbine is maintained constant, but the relative amounts of pressure above the turbine and draft below the turbine are varied, a point is reached at which the model suddenly changes its characteristics. This has been ascribed to cavitation,

* The Bureau of Standards did not contemplate including progress reports of the nature and length of the following in the quarterly reports on hydraulic research. However, the material in the report submitted by the Safe Harbor Water Power Corporation is of such great interest to a wide circle of investigators and engineers that it was decided to include it in the present quarterly report.

or the breaking away of the water from some part of the runner blade. It was assumed this cavitation would take place when the pressure at any point was reduced to that of the vapor pressure of the water.

Dr. Thoma introduced the use of the cavitation coefficient, commonly called sigma, which can best be visualized by imagining a turbine tested under constant head but with the draft head progressively increased. Suppose then that at the point when an abrupt change in discharge and output was noted, the turbine gates should be closed. The pressure that would exist on the runner blades after gate closure is obviously the barometric height minus the draft head, in other words the distance above tailwater. In accordance with the theory outlined above, it was believed that while running, the pressure at some point was reduced to the vapor pressure of the water. Therefore, the difference between the static pressure with gates closed and the vapor pressure is a measure of the pressure reduction, which is a characteristic of the design. As this reduction is proportional to the square of the velocity of water, which is in turn proportional to the square root of the head, it may be expressed as a percentage of the total head. This percentage is commonly called the cavitation coefficient, sigma.

Although subsequent experiments by Prof. Spannhake have shown that a break in similitude can come even without the presence of cavitation, nevertheless Dr. Thoma's work has been of great service in furthering the intelligent design of propeller runners. As far as can be seen at present, the results from this method of testing are at least conservative and have been useful in showing what influences are conducive to cavitation.

There are now several laboratories on this continent equipped to test the cavitation characteristics of model runners.

Although much experimental work has been devoted to models themselves, it was felt by the Safe Harbor Water Power Corporation that little attention had been given to the fundamental theories and determination of the exact nature of the process. Therefore, in addition to the laboratory studies conducted at Holtwood supplemented by field observations and inspections, opportunity was taken of securing the services of Prof. Spannhake, who in the fall of 1931 succeeded Dr. Thoma as Visiting Professor of Hydraulics at the Massachusetts Institute of Technology.

Prof. Spannhake came to this country having had considerable experience in his own laboratory at Technische Hochschule, Karlsruhe, Baden, Germnay. His apparatus differed from Dr. Thoma's inasmuch as the water was confined in a closed system, the turbine being located between two tanks, the pressure in both of which could be varied as desired. Such an arrangement had the advantage that tests could be conducted at widely varying heads, inasmuch as the whole was removed entirely from the effect of atmospheric pressure. This fact subsequently proved very important as it made possible a series of supplemental experiments showing that the problem was not as simple as had been supposed.

Prof. Spannhake's views on the subject of cavitation were excellently summarized in a paper which he presented before the Hydraulic Power Committee of the National Electric Light Association, Publication No. 222, February 19, 1933. In brief the action is believed to be essentially mechanical rather than chemical. Bubbles of vapor are formed as soon as the pressure at any point of a turbulent, or impure, liquid is reduced to the vapor pressure. If air is present, even in a very small quantity, it comes out of solution prior to the formation of vapor. When a bubble is formed it will contain not only vapor, but a mixture with air. Though readily drawn out of solution by a reduction in pressure, the air finds difficulty in redissolving at the moment of collapse of the bubbles, and consequently remains to receive the concentrated energy of the inrushing walls of water. It was not definitely known what form this concentrated energy may take, but it was believed that although the bubble was surrounded by a cooler medium, and although it must have a very small ratio of volume to surface, nevertheless for an exceedingly small period of time it must be compressed to an enormous pressure and at the same time heated to a high temperature. Now should the small particle of concentrated energy happen to come in contact with a solid surface in which there are minute fissures, the bubble of air may become lodged and then either explode with tremendous violence, or transmit sufficient heat to its surroundings to raise the temperature to the melting point, or in any case it may easily cause the particles in the surface to become dislodged so that the material itself would disintegrate. The experiments at M.I.T. were undertaken largely to test this theory, and to determine precisely why cavitation should have the effect it does upon the bounding surfaces.

It had already been known that cavitation has a very marked effect upon glass, for in some of Prof. Spannhake's earlier work this has been noted, and for this reason it was believed that the pitting was not essentially of chemical nature. Not only is glass subject to pitting, but it is one of the most vulnerable of materials known. It is believed that the particular quality which contributes to weakness in this respect is the extreme brittleness.

In order to carry out these researches, Prof. Spannhake proposed to produce cavitation under controlled conditions. The necessary apparatus was erected consisting of two centrifugal pumps which could be connected in parallel or series, a large head tank where the discharge from the pumps could become quiet, the test section which consisted of a Venturi shaped passage of rectangular cross-section in which cavitation was produced, and a return line to the pumps. This test section was provided with glass windows to allow inspection of the phenomenon.

The first experiments were carried out in the passage having an upstream flare of 20 degrees on each side, extending for 4 3/8" from the throat which was 2.95" by 4" wide. From this point there was an expanding section 3-1/2 degrees on each side and 15 5/8" long terminating in a section 4.84" by 4" wide. These experiments led to interesting studies of pressure distribution and showed in general the characteristics of the formation of cavitation. As could be expected, the lowest pressure was found at the throat or narrowest cross-section. Until the pressure at

this point was lowered practically to the vapor pressure of the water corresponding to the temperature, there appeared to be strict obedience to the laws of similitude, that is to say, the pressure difference between any two points in the system was proportional to the pressure difference between any other combination of two points.

On further increase in velocity, or decrease in pressure, which itself would tend to lower the pressure at the throat even below that of the vapor pressure, there was a definite change in the pressure distribution. The curve of pressure as a function of distance then became fixed up to the throat while beyond the throat there would be a zone of practically constant pressure substantially equal to the vapor pressure followed by an abrupt rise which resembled very closely the water surface in the hydraulic jump.

One observation that was disappointing at the outset, but significant in the end, was that however conditions would be varied, no pitting was found in this section and no destructive effect could be produced. Another observation which almost passed unnoticed was the fact that there was a slight change in the distribution of pressure upstream from the throat just before the vapor pressure was reached at the throat. Experiments subsequent to the publication of this report have shown that this effect may have considerable importance, for it is shown definitely that similitude may break down before the actual appearance of cavitation.

The test section was then altered by increasing the downstream flare and making it terminate in a portion with parallel sides. A marked difference in behavior was readily noted, for by manipulating the pressures to extend the zone of cavitation, it was found that when the point of collapse, which is coincident with the sudden rise in pressure described above, reached the junction of the flare and the parallel portion, there was a sudden increase in noise. Furthermore, pitting began to be noted on the glass windows, and in a short time this would progress far enough to break them. Considerable care had to be exercised to prevent rapid failure of the windows and they were replaced for experiments under the more severe conditions by steel plates. As experience was gained, it was found that glass plates could be used almost indefinitely by passing through the conditions conducive to pitting as quickly as possible.

Study of pressure distribution revealed an unexpected result, which was that the laws of similitude held at least within the limits of observation, for the portion of flow downstream from the zone of cavitation.

It was realized early in the work that account must be taken of air contained in the water, which undoubtedly would have considerable influence on the pressure in the bubbles, and possibly the nature of the pitting Little seemed to be known in regard to the behavior of water containing air in solution when subjected to pressures below that at which the air had been dissolved. To determine the amount of air actually present,

an analyzer was made based upon a mechanical rather than chemical principle. A small sample of water was taken directly from the tank to be submitted to as nearly the same physical treatment as possible to that which it receives when passing through the zone of cavitation. The apparatus was extremely simple, and consisted of a small vessel connected to a calibrated burette in which a vacuum could be drawn by lowering a reservoir of mercury connected to it by means of a flexible tube. After the air had been extracted in this way the amount was found by simple application of Boyle's Law.

In the course of this work, Dr. H. Peters, of the Aeronautical Department, who was then in charge of the work in Prof. Spannhake's absence, made an important observation, that if the upper part of the burette were filled with water under ordinary pressure and the reservoir then lowered, thus reducing the pressure, the water started to effervesce, or give off its dissolved air, when the unbalanced column of mercury stood at approximately one-half of the barometric height. That is to say, when water for any reason is subjected to pressures lower than that for which it gives off its dissolved air, there is a change of volume and the fundamental equation $Q = A V$ no longer holds. He also found that although there was little difficulty in extracing a large part of the air from the water by such treatment, the air once removed showed a great deal of reluctance to redissolve without turbulence. On one occasion he allowed the apparatus to stand overnight without a measurable return of air into solution.

Subsequent experiments have shown that cavitation has the effect of reducing the amount of air carried in solution, and although the air returns to the pumps along with the water which once held it, the turbulence in the pumps and water passage is not sufficient to redissolve it as fast as it can be drawn out by passage through the zone of cavitation. This is a possible explanation for the fact that bubbles of air are seen rising from the draft tubes of hydraulic turbines. It has also been demonstrated that without cavitation air admitted to the system at a point of low pressure and allowed to pass through the pumps will dissolve. Apparently the cavitation will more than offset this effect, for the water becomes depleted of much of the air in solution.

In the experiments so far, little information had been secured regarding the actual pressures existing in the zone of cavitation. A great many difficulties have been encountered, and special care must be exercised to secure reliable results, for unless this is taken, the manometer readings may be influenced by many effects such as the boiling of any water caught in the manometer connections, etc. The more recent experiments using a section 4" by 4" and about 10" long instead of a throat as before indicate that the pressure where cavitation begins is greatly influenced by the fact that the air in the water now has a longer time to come out of solution. This is a subject for further investigation.

The apparatus designed by Prof. Spannhake offers not only an opportunity for fundamental research, such as studies of pressure distribution, etc., but also makes possible practical tests of materials by subjecting them to the effect of cavitation. In order to accelerate the results, it was desirable to find the shape of the passage which would produce the most violent effect. It had been found that increasing the flare led to increasing violence, and, therefore, it was decided to go to the limit and try a sudden enlargement. Results were at first disappointing for the action was not particularly severe. Cavitation was actually produced, but the pitting on the glass windows proceeded at a very slow rate. As far as could be judged, the water formed for itself a natural Venturi section with sufficient flexibility to accommodate itself to varying pulsating pressures so that the cavitation took place within the water itself rather than in contact with the metal walls.

In order to subject a sample to the fury of the collapsing bubbles, a cylinder of cast iron was mounted so that it would extend across the channel. The cast iron was examined and found not to have suffered at all. The results though disappointing, indicated that simply presence in the zone of cavitation was not sufficient to assure that pitting would take place. This experience has led to the belief that there is a protecting influence in the stagnation pressure about such an obstacle which prevents the contact of the collapse with the surface.

Subsequent experiments were then made by increasing the flare until it was finally decided that a profile, known as profile 3, would be satisfactory for use in connection with endurance tests. It is interesting to note that in spite of the long and severe use, the surface is still smooth up to the junction between the flare and the parallel portion, but beyond this the metal has been severely hammered.

Moving pictures have been taken by Prof. Edgerton with his stroboscope at the rate of nearly one-thousand exposures per second, and show in a most interesting manner that two clouds of vapor form one on each side of the passage downstream from the throat. These grow, keeping at all times almost exactly equal in length, until a point is reached beyond the beginning of the parallel portion when suddenly there is a bridging across from one cloud to another. A core of a vortex can be distinguished with axis at right angles to the direction of the flow extending from one cloud to the other just before they merge. At the same time there is a distinct necking down of both the clouds, so that they are both cut in two in a few thousandths of a second. After that the outer portion almost instantly vanishes leaving the inner portion to repeat the operation with a frequency of about twenty times a second. It is supposed that there is a similarity between the regain in pressure in the zone of collapse and the hydraulic jump which in turn is known to be unstable in a parallel channel. There is possibly a relation between this sudden fluctuation of unstable phenomena and a scrubbing away of a protecting layer of slowly moving water, and this is what exposes the metal surface to the collapse of the bubbles.

Based on the fact that the sudden enlargement did not produce violent cavitation or damage to the metal and the fact that possibly the boundary layer may protect the metal surface, experiments have been made with frets welded to the metal surface to hold the collapse of the bubbles at a safe distance. After considerable exposure no pitting was found on the plates so protected.

The present indications are that the effect of cavitation upon a ductile material such as brass is a severe hammering or peening action. Thin brass sheets were fastened by screws to cast iron plates, and after exposure were found on releasing the screws to be severely buckled showing evidence that a compressive strain had been forced into the surface. Cast iron and semi-steel were found to be affected by apparent eating away of the graphite leaving the perlite in minute lumps exposed in a way which resembled the surface of concrete in which there was not enough paste to fill in the spaces between the gravel.

A few experiments were tried with paints which showed very little resistance to the hammering effect, but on the other hand such tests were useful in indicating where the severest cavitation was taking place. One test, unsuccessful in itself, showed very plainly that there was a marked difference in exposure between the flaring and the parallel portion. That is to say, paint that showed no effect in the flare could be flaked off in half an hour in the parallel section. On the whole, the few paint tests that were run indicated if anything a greater resistance on the part of paints which were applied by spray rather than those which were applied by brush.

Of greatest interest are the experiments which have been made with rubber. Through the courtesy of a prominent rubber company, plates were secured covered with rubber 3/8" and 5/16" thick respectively, These were tested for forty hours without any apparent change, in fact the print of the fabric used in applying the coating could still be distinctly seen.

Desiring to know whether it was the thickness of the rubber which gave it its resistance, similar plates were furnished coated with 1/8" and 1/16" rubber respectively. These showed apparently the same resistance.

In spite of the failure of the paints, one manufacturer submitted a sample coated with rubber paint which came through a test of forty hours without any damage that could be detected. Further tests are in progress for determining the suitability of rubber for application to turbine runners.

In conjunction with these tests, Prof. Spannhake had his laboratory in Karlsruhe equipped for cavitation tests to cover a wide range of heads. He had intimated in his talk in February, 1932, that theoretical considerations indicated that the ratio of the diameter of the runner to head should have a slight influence on the value of sigma. He has pointed out that in models this ratio might be in the order of a few per cent, whereas in prototypes

it might amount to as much as one-third. As a result of these experiments he found that the effect was greater than had been anticipated. A possible explanation is the influence of air contained in the water. Experiments are now in progress which have indicated so far that there is at least danger in neglecting air from consideration in hydraulic design, particularly where water is subjected to pressures less than that at which it comes in free contact with air. Experiments with the passage in which the zone of low pressure is longer have not only confirmed the previous observation of breaking down of similitude without formation of cavitation, but have shown that bubbles of air actually do come out of solution and can be seen flowing through the section upstream from the point where cavitation begins. It has been shown that the pressure distribution can be changed not only without cavitation, but also when the lowest pressure in the system is well above the vapor pressure.

It may be concluded, therefore, that in the design of hydraulic equipment the influence of air cannot be neglected, and that there are many possibilities of disturbing influences arising from this fact.

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DIRECTORY.

(Laboratories for which projects are listed in this report.)

California Institute of Technology,
Pasadena, California. (pp. 2 and 3.)

University of California,
College of Engineering,
Berkeley, Cal. (pp. 4-6.)

Harvard University,
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Hydrological Laboratory,
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Iowa Institute of Hydraulic Research,
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Michigan State College of Agriculture and
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National Hydraulic Laboratory,
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Pacific Hydrologic Laboratory,
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